Resilience Assessment of Coupled Water-Agriculture-Community Systems - Using System Dynamics Modeling

(Lower Rio Grande, New Mexico State)

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Overview

- Problem Statement
- Resilience Theory
- Framework
- System Dynamics Model
- Results
- Conclusion

Problem Statement

- **Since 2002, prolonged droughts have led to:**
  - Significant reduction in snowmelt
  - Reduction in surface water supplies
  - Increasing pressure on groundwater

- **These challenge threatens the Water, Agriculture, and Community Systems (WACS) in this region.**

- **Therefore, increasing the Resilience of these systems in coping with climate change is vital.**

- **Questions:**

  1- How to assess the resilience of the WACS?

  2- How to enhance the resilience of the WACS?

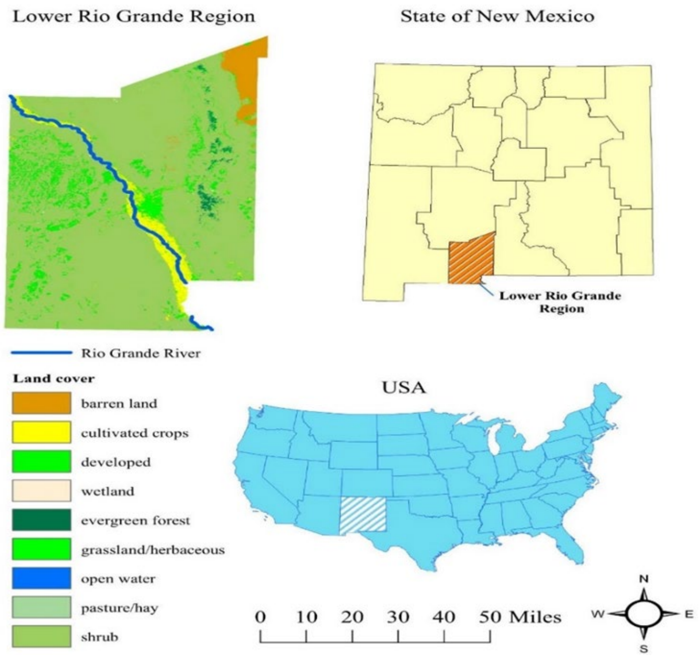


Figure 1. Location of Lower Rio Grande Region and its land cover (Bai et al., 2021).

Resilience Definition and Theory

- Resilience is an inherently complex concept within the literature on Social-Ecological Systems (SES).

- The diversity in theories and definitions of resilience reflects a broad range of assessment approaches.

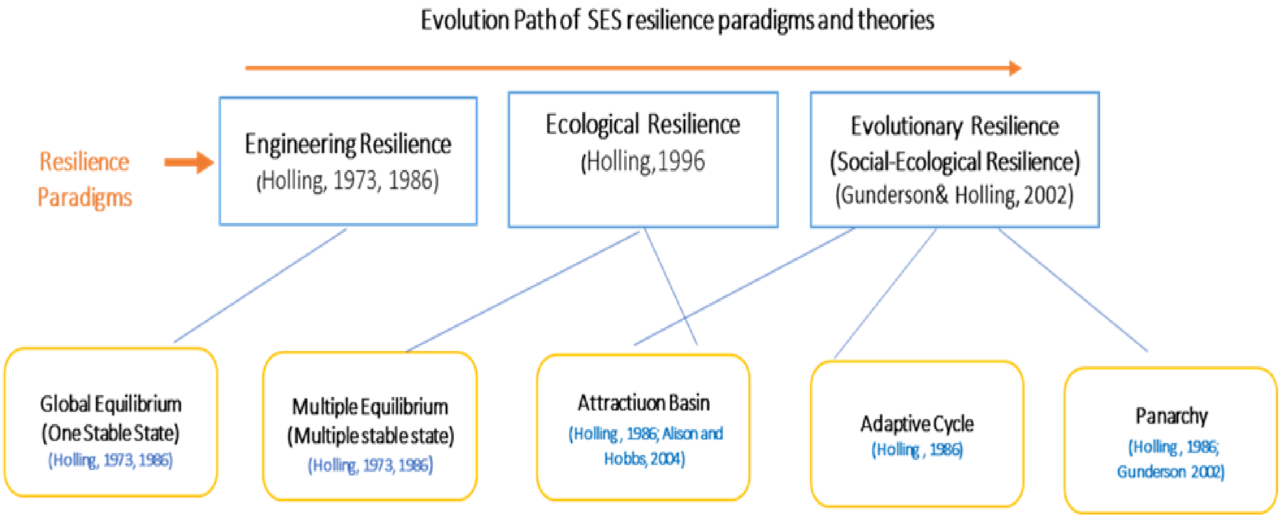


Figure 2. Evolution Path of Theories used for Resilience definition and application in SESs

Resilience Definition and Theory

- Assessment of resilience without considering dynamic structure and feedback loops often misses the critical component of resilience.

- Many studies overlook the dynamics and feedback loops in the resilience assessment of social-ecological systems (SES)

Table 1. Summarizing the approaches to assessing resilience in SES.

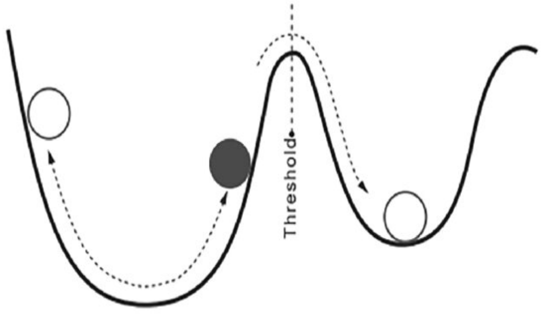
Approach	References
Indicator-Based Assessment (IBA)	Li et al., 2020; Costa et al., 2023; Soriano et al., 2023; O'Connell et al., 2015
Early Warning Signs (EWS)	Kaiser-Bunbury et al., 2017; Biggs et al., 2018; Chuang et al., 2018; Li et al., 2020
Stakeholder Assessments	Darnhofer et al., 2010; Carper et al, 2021
Historical Profiling	Bennett et al., 2005; Cumming et al., 2005
Case Study Comparison	Burgess et al., 2019; Li et al., 2020
Multi-Agent Models	Filatova et al., 2016; Chuang et al., 2018; Li et al., 2020
Participatory Modelling	Talubo et al., 2022; Noble et al., 2021; Carper et al, 2021
Differential Equations	Todman et al., 2016; Carper et al, 2021
Network-Based Approach	Zhang and Wang, 2023; Chen et al, 2019
Feedback-Based Approaches	Herrera and Kopainsky; 2020; Oliveira et al, 2022; Zhang and Wang, 2023

We Applied:

- System Dynamics
- Attractive basin theory & the Adaptive cycle

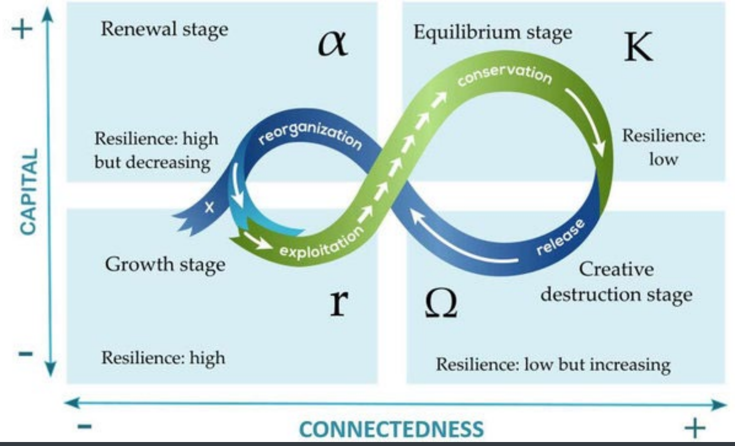
Resilience Definition and Theory

Figure 3: Ecological Resilience:
Resilience is the ability or capacity of a system to absorb disturbances and maintain its **structure and function** before undergoing a regime shift.



Ecological resilience concept

Figure 4. The adaptive cycle theory :
The adaptive cycle includes four phases: exploitation (r), marked by rapid growth and resource abundance; conservation (K), where growth slows and efficiency increases; release (Ω), triggered by disturbance and system breakdown; and reorganization (α), where new structures and opportunities for adaptation emerge



Framework: Function-Based Resilience Assessment

Hypothesis:

- The water–agriculture–community system (WACS) in the LRG is not resilient in response to climate change.

- Improving water conveyance efficiency enhances the resilience of WACSs in coping with climate change in the LRG.

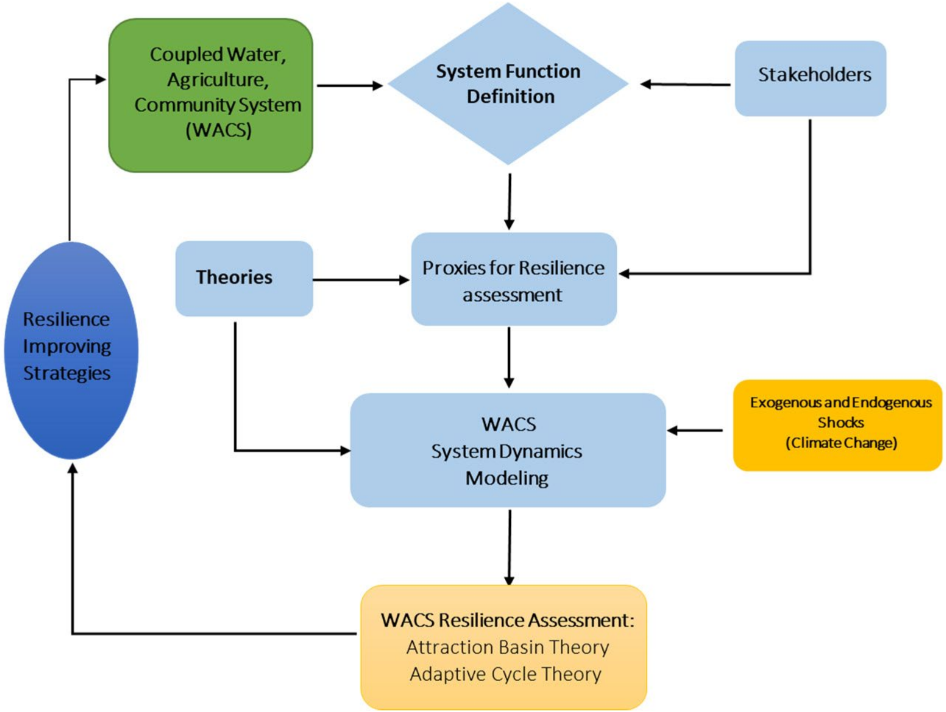
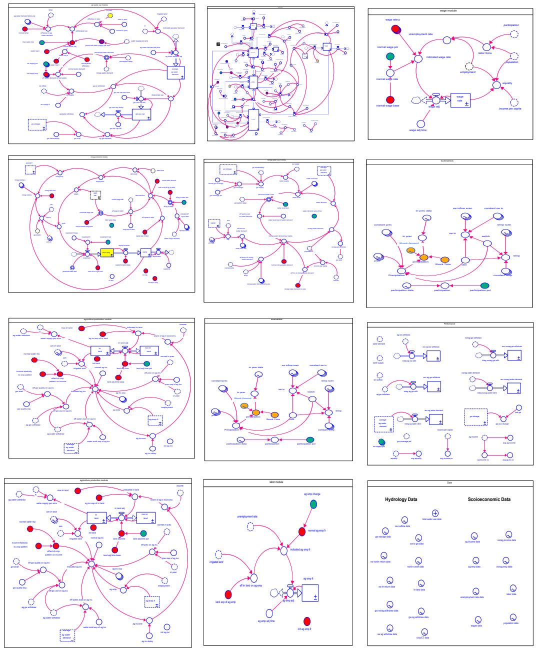
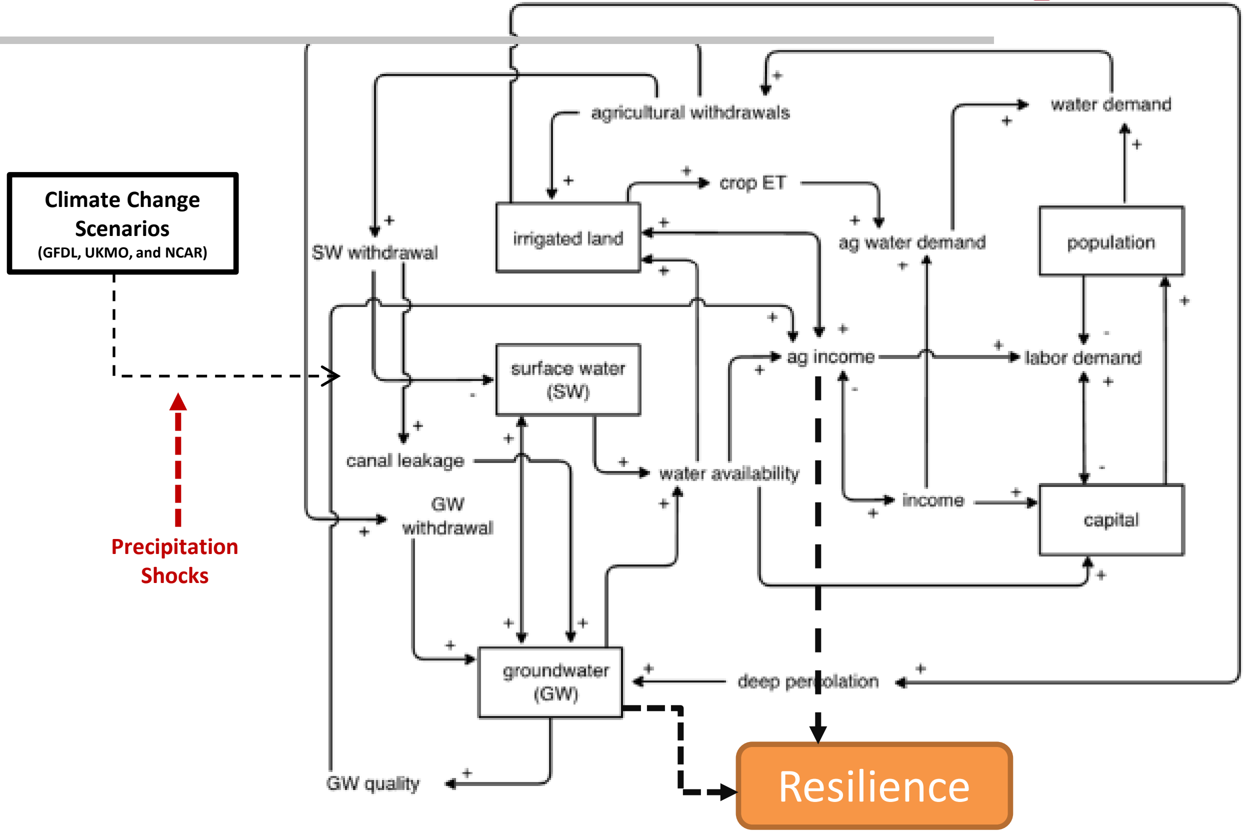


Figure 5. The framework of function-based resilience assessment for coupled Water–Agriculture–Community Systems (WACSs).

System Dynamics Model



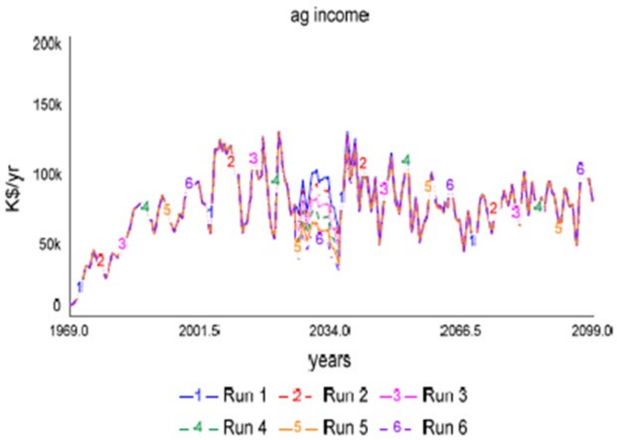


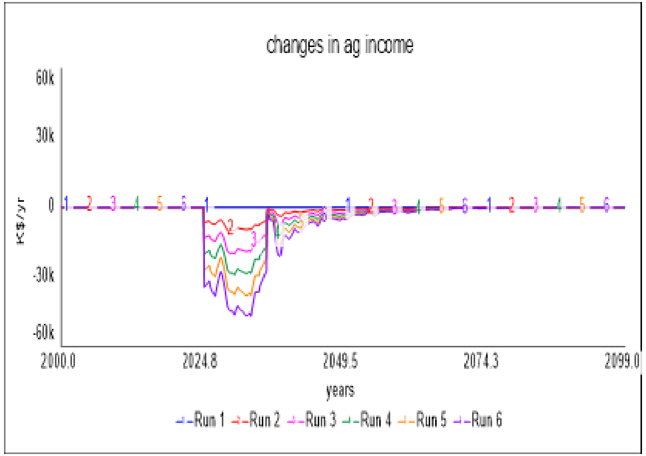
Geophysical Fluid Dynamics Laboratory (GFDL)
United Kingdom Met Office (UKMO)
and National Center for Atmospheric Research (NCAR)

Fig 5:NMWRRI Offshoot SD model (Langarudi et al, 2019).

Results

- **Resilience Assessment of WACSs – Attraction Basin Theory**





a. Agricultural Income in UKMO climate scenario

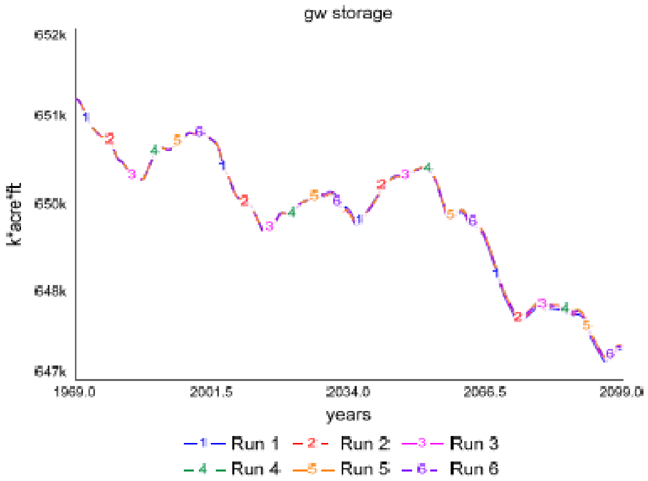
b. Agricultural Income changes in UKMO climate scenario

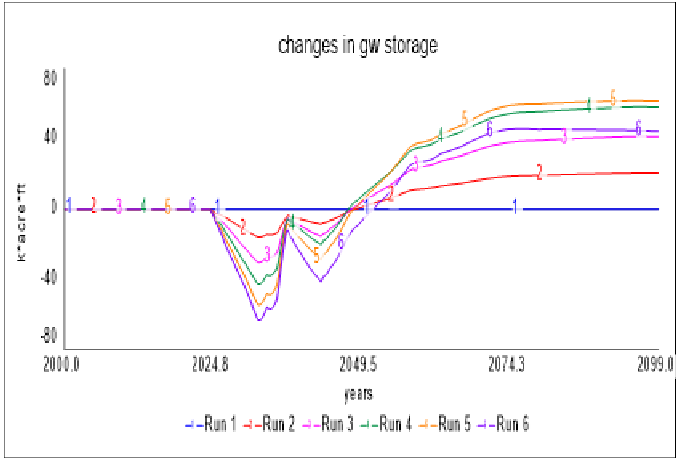
Figure 6. Agriculture Income and its changes simulation under UKMO climate scenarios – after climate shock

- The impact of precipitation changes on the resilience of the system was assessed in different climate scenarios, including UKMO, GFDL, and NCAR.
- The imposed shock reflects a reduction ranging from 10% to 50% over a period of 10 years from 2025 to 2035

Results

- **Resilience Assessment of WACSs – Attraction Basin Theory**





a. Groundwater storage in UKMO climate scenario

b. Groundwater storage changes in UKMO climate scenario

Figure 7. Groundwater Storage and its changes simulation under UKMO climate scenarios – after climate shock

Results

- **Resilience Assessment of WACSs – Adaptive Cycle Theory**

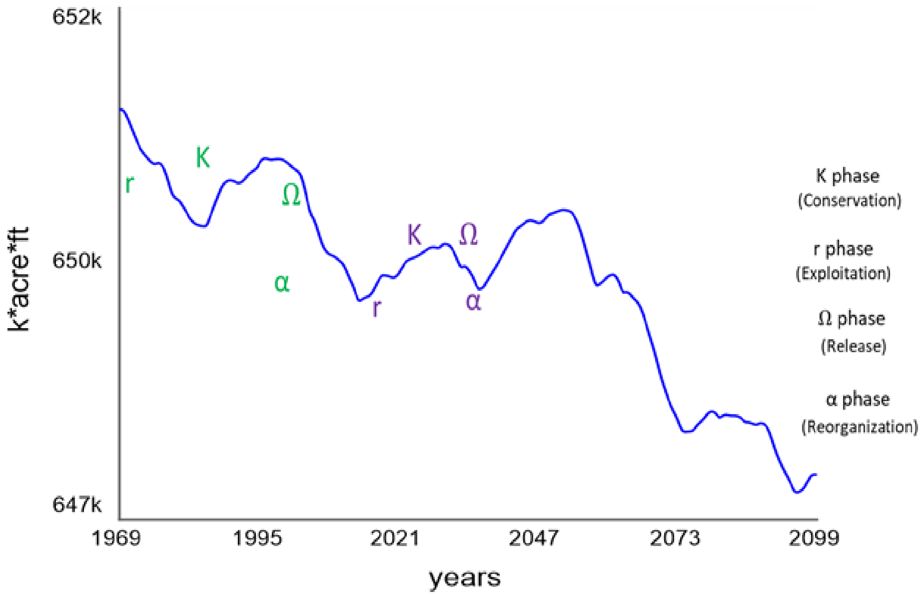
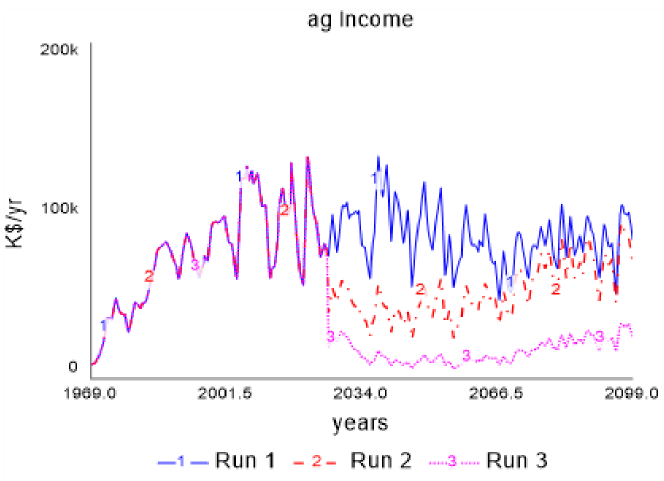


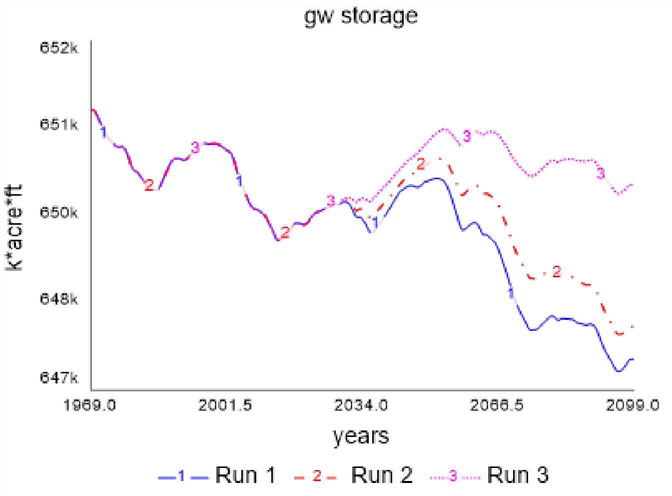
Figure 8. Dynamics of Groundwater Storage on the basis of adaptive cycle theory, model simulation on baseline scenario, UKMO

Results

Strategy for improving WACS Resilience – Surface water Conveyance Efficiency Improvement



a. Agricultural Income in UKMO climate scenario



b. Groundwater storage in UKMO climate scenario

Figure 8. Groundwater Storage and Agriculture Income simulation after improving conveyance efficiency in different climate scenarios including UKMO

Conclusions

- The varying outcomes across the MED, LOW, and HIGH climate scenarios illustrate the sensitivity of WACSs resilience to climatic conditions and interventions.
- While the hydrological part of the system, represented by groundwater storage, exhibited signs of resilience, under enhanced water conveyance efficiency, the agricultural-community part consistently struggled to adapt or reorganize effectively in response to climate shocks or efficiency improvements.
- Groundwater storage generally benefited from increased surface water conveyance efficiency, highlighting the potential of infrastructure improvements to mitigate some hydrological risks. However, these benefits did not extend to the agriculture–community function, which remained vulnerable across all scenarios.
- Our findings emphasize that resilience-building in WACSs requires a system approach that addresses both environmental and socioeconomic dimensions.

Thank You